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Seed predation, myrmecochory, seed viability and seed germination in *Croton scabiosus* Bedd. (Euphorbiaceae), a deciduous endemic tree species in the southern Eastern Ghats of Andhra Pradesh, India

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ABSTRACT

In *Croton scabiosus*, seed predation occurs in pre-dispersal stage. An insect species (unidentified) uses flower buds as ovi-position sites and the adults emerge during fruit maturation stage. Then, the larva uses the developing endosperm and embryo as food and the adult takes exit from the chalazal end of the seed and fruit. Pre-dispersal seed predation is 57% to 64% during January-June flowering season and 74% during September-October flowering season. This study finds that high rates of seed predation has great implications for population dynamics of this plant. *Camponotus* ants use the caruncle of seeds as food and disperse seeds in this feeding activity. But, the success rate of seed dispersal is attributed to the total seed quantity not used by ants. *C. scabiosus* seeds are viable for more than one and half year but viability percentage varied; it is highest immediately after seed fall to the ground and lowest after one and half year. The seed germination rates in different soil media, red soil in combination with manure and super-phosphate, red soil alone, black soil and sandy soil indicated that red and black soil types provide favorable conditions for seed germination. But, the natural habitat of the plant characterized by rocky terrain with low levels of red sand mixed with black soil is unfavorable for high seed germination rate as there is only a small population representing scattered individuals at both the study sites. Therefore, the study recommends further field studies on seed predation and *in situ* soil analysis to take effective measures for *in-situ* conservation and population buildup of *C. scabiosus*.

Key words: *Croton scabiosus*, seed predation, seed viability and seed germination.

1. INTRODUCTION

Seed production is a part of the process of reproduction in seed plants. A seed is a product of the fertilized ovule, an embryonic plant enclosed in a protective outer covering (Miles and Brown, 2007). Seed is the basic component in plant sexual reproduction and provides energy, nutrients and raw materials for humankind (Nongaki 2012; Dante et al. 2014). Seeds generally germinate when soil moisture and temperature conditions are correct for them (Miles and Brown, 2007). They can tolerate very severe heat, cold, desiccation, and high pressure. These attributes are treated as ultimate means of survival of species and their populations.

Seeds are prone to predation by different classes of animals during pre-dispersal and post-dispersal phase. The protection of seeds from their predators is a huge task for the plants. The seeds are important food source for animals such as mammals, birds and insects. Janzen (1970) noted that seed predators either consume them completely or damage them due to which seed germination is not possible. Seed predation is more during pre-dispersal phase (Crawley 1992) while seed predators alter the surviving seed shadow by their searching strategy/efficiency (Harper 1977). Seed predators represent two categories; the first one is specialized, short-lived and the second is long-lived. In short-lived species, their phenology synchronizes with the host plant phenology. In long-lived species are mostly polyphagous vertebrates and feed opportunistically on different species at different times during pre- or post-dispersal stage (Harper 1977). The temporal and spatial distribution of seed germination is very critical for survival and proliferation of seed plants. The physiological status of seeds is important for temporal distribution while seed and fruit morphology is important in spatial distribution (Bewley et al. 2013). In some plant species, the mature seeds are incapable of germination even in ideal conditions indicating the requirement of certain environmental conditions to break seed dormancy for germination (Bewley 1997). Hassan and Fardous (2003) noted that it is a very difficult task to understand the seed biology involving various aspects starting from seed production to seed germination. However, the knowledge of various aspects of seed biology is important to understand the factors controlling or influencing or providing environmental stimuli for seed viability, dormancy and germination as this information is essentially required for understanding the population dynamics of plant species and also for *in situ* or *ex situ* conservation and management of populations of individual plant species, especially those included in IUCN Red list.

Keeping the importance of seed biology in view, the work on seed predation, seed viability and seed germination responses to different soil types was undertaken for *Croton scabiosus* Bedd. (Euphorbiaceae), a small deciduous and endemic tree species in the Southern Eastern Ghats of Andhra Pradesh, India. These aspects have been explained in the light of relevant literature.

2. MATERIALS AND METHODS

Fruit infestation:

Fruits were collected randomly from different branches of ten trees each during January-June flowering season of 2018 and 2019 at Palakondalu and Idupulapaya study sites in Kadapa District, Andhra Pradesh, India. In Idupulapaya site, fruits were collected also during September-October flowering season of 2019 (Figure 1a-d). The collected fruits were brought to the laboratory and dried completely in sunlight. Then fruits were carefully observed to record fruit infestation rate. The infested fruits from the total sample of fruits were separated and calculated for the percentage of infested fruits. Flower buds collected from the plant were observed to note whether any eggs or larvae or adults were inside them.

Seed viability:

A sample of eighteen hundred seeds was collected from Palakondalu study site in June and stored them in the laboratory. Seed viability was tested using one hundred seeds each time in each month 18 consecutive months. The chemical 2, 3, 5 Tri Phenyl Tetrazolium Chloride was used to test seed viability (Chiruvella et al. 2014). Prior to test, the embryo and endosperm (creamy white) together were separated from seed coat (ash colour) and then tetrazolium chloride was applied for color change. The color change from creamy white to brick red was taken as an indication of viable seed while color change to light yellow was taken as an indication of in-viable seed. Then, the total number of viable seeds was counted for each sample of seeds used in each month and then the percentage of seed viability was calculated.

Effect of different pot media on seed germination:

Seed germination percentage in different pot media was carried out at the nursery site of Idupulapaya. Five soil media were used in different combinations to evaluate seed germination rate. The media were red soil, black soil, red soil + sand, sand, red soil + manure + super phosphate (3:1:1). One hundred polythene bags were used for each medium. In each bag, the soil medium was

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placed and then one seed was slightly buried in this medium, and followed for about one month. The first date of seed germination in each medium was recorded and then the percentage of seed germination was calculated from hundred bags for each medium.

Effect of different pot media on seedling growth, production of leaf pairs and biomass production:
The experiment conducted for seed germination in different media - red soil, black soil, red soil + sand, red soil + manure + super phosphate (3:1:1) was continued for more than 12 months to record root length, shoot length, number of leaf pairs, root fresh and dry weights, shoot fresh and dry weights. The seedling measurements, number of leaf pairs and biomass production increase were recorded at different time intervals, after 1-month, 3-months, 6-months, 9-months and 12-months. This experiment was conducted to determine the importance of different soil media on the aspects studied during seedling stage.

3. RESULTS

Fruit infestation and seed predation: An unknown insect species was found to be using the flower buds for depositing its eggs. The eggs produced larvae which formed adults during fruit maturation stage. The adults made a hole at the chalazal end of the developing seed and then bored a hole through the pericarp of the fruit in order to take exit (Figure 1e, Figure 2a-e). In each fruit, the number of larvae or adults corresponded to the number of ovules/seeds; the endosperm of each developing seed was used by the larva of the insect as food reserve and subsequently moved out of the seed and fruit pericarp during green color stage of the fruit. The seeds that were used by this insect were empty while those that were not used by it were stuffed with endosperm along with the embryo. The *Camponotus* ants which were involved in using the caruncle of the seed as food invariably moved the infested and un-infested seeds as the caruncle was intact due to boring of hole by the adult insect on the opposite end of the caruncle. Fruit infestation rate varied with each study site and also with the flowering season in case of Idupulapaya site. The fruit infestation rate was 57% during January-June flowering season at Palakondalu site while it was 64% during January-June flowering season and 74% during September-October flowering season at Idupulapaya site (Table 1).

Table 1. Fruit infestation rate in *Croton scabiosus*

Study site/flowering season	No. of fruits sampled	No. of infested fruits	Fruit infestation (%)
Palakondalu			
January-June flowering season	3301	1891	57
Idupulapaya			
January-June flowering season	2869	1845	64
September-October flowering season	1602	1185	74

Table 2. Results of seed viability tested with 2, 3, 5 Tri Phenyl Tetrazolium Chloride (TTC) in *Croton scabiosus* over a period of 19 months

Month	Seed samples	No. of viable seeds	Seed viability (%)
July	100	80	80%
August	100	72	72%
September	100	60	60%
October	100	55	55%
November	100	52	52%
December	100	40	40%
January	100	36	36%
February	100	30	30%
March	100	24	24%
April	100	20	20%
May	100	18	18%
June	100	15	15%

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July	100	13	13%
August	100	11	11%
September	100	9	9%
October	100	5	5%
November	100	3	3%
December	100	2	2%
January	100	0	0%

Table 3. Effect of different pot media on seed germination in *Croton scabiosus*

Soil Type	No. of seeds sowed	Time taken for seed germination	No. of seeds germinated	Germination (%)
Red Soil	100	15-18 days	80	80
Black Soil	100	21-23 days	53	53
Red Soil + Sand	100	24-26 days	32	32
Sand	100	19-21 days	20	20
Red Soil + Manure + Super phosphate (3:1:1)	100	13-16 days	80	80

Date of seeds sowed: 21.06.2016

Table 4. Seedling measurements (± SE) and biomass production in *Croton scabiosus* in red soil medium in open field conditions after 1, 3, 6, 9 and 12 months

Aspect	After 1-month	After 3-months	After 6-months	After 9-months	After 12-months
Root length (cm)	2.4 ± 0.35	3.8 ± 0.94	4.1 ± 0.78	5.2 ± 0.64	14.9 ± 3.55
Shoot length (cm)	1.32 ± 0.25	2.46 ± 0.40	2.94 ± 0.81	3.28 ± 0.58	13.74 ± 1.40
Number of leaf pairs	1-2	3-6	4-9	6-11	12-16
Root fresh weight (gms)	0.40 ± 0.40	0.60 ± 0.03	1.1 ± 0.03	2.2 ± 0.13	4.74 ± 1.34
Root dry weight (gms)	0.13 ± 0.01	0.34 ± 0.02	0.54 ± 0.09	1.2 ± 0.20	3.94 ± 1.26
Shoot fresh weight (gms)	0.16 ± 0.02	0.19 ± 0.03	0.34 ± 0.06	1.3 ± 0.43	3.88 ± 1.31
Shoot dry weight (gms)	0.13 ± 0.01	0.15 ± 0.04	0.38 ± 0.20	0.46 ± 0.32	2.45 ± 1.19

Table 5. Seedling measurements (± SE) and biomass production in *Croton scabiosus* in black soil medium in open field conditions after 1, 3, 6, 9 and 12 months

Aspect	After 1-month	After 3-months	After 6-months	After 9-months	After 12-months
Root length (cm)	2.16 ± 0.18	2.50 ± 0.28	3.90 ± 0.55	4.06 ± 0.85	14.10 ± 2.75
Shoot length (cm)	1.24 ± 0.26	2.24 ± 0.73	2.34 ± 0.37	2.96 ± 0.55	11.80 ± 1.53
Number of leaf pairs	1-2	3-6	5-9	6-11	12-15
Root fresh weight (gms)	0.22 ± 0.03	0.34 ± 0.31	0.67 ± 0.31	1.72 ± 0.13	6.01 ± 1.24
Root dry weight (gms)	0.14 ± 0.01	0.18 ± 0.07	0.56 ± 0.11	1.20 ± 0.08	4.57 ± 1.06
Shoot fresh weight (gms)	0.28 ± 0.28	0.42 ± 0.27	0.64 ± 0.31	1.34 ± 0.15	5.40 ± 1.20
Shoot dry weight (gms)	0.24 ± 0.11	0.31 ± 0.16	0.45 ± 0.08	0.86 ± 0.03	3.50 ± 1.13

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Table 6. Seedling measurements (± SE) and biomass production in *Croton scabiosus* in red soil and sand medium in open field conditions after 1, 3, 6, 9 and 12 months

Aspect	After 1-month	After 3-months	After 6-months	After 9-months	After 12-months
Root length (cm)	2.06 ± 0.08	2.2 ± 0.1	2.9 ± 0.93	3.28 ± 0.33	7.16 ± 0.72
Shoot length (cm)	1.16 ± 0.18	1.48 ± 0.41	2.34 ± 0.57	2.46 ± 0.15	3.92 ± 0.59
Number of leaf pairs	1-2	3-4	4-5	6-9	7-10
Root fresh weight (gms)	0.38 ± 0.08	0.58 ± 0.37	0.61 ± 0.40	1.23 ± 0.34	2.45 ± 0.29
Root dry weight (gms)	0.26 ± 0.05	0.32 ± 0.05	0.41 ± 0.21	0.87 ± 0.18	1.38 ± 0.37
Shoot fresh weight (gms)	0.34 ± 0.13	0.62 ± 0.31	1.40 ± 0.40	1.92 ± 0.39	4.90 ± 0.86
Shoot dry weight (gms)	0.16 ± 0.05	0.34 ± 0.05	0.76 ± 0.13	1.02 ± 0.28	3.74 ± 0.60

Table 7. Seedling measurements (± SE) and biomass production in *Croton scabiosus* in red soil, manure and Super Phosphate (3:1:1 ratio) in open field conditions after 1, 3, 6, 9 and 12 months

Aspect	After 1-month	After 3-months	After 6-months	After 9-months	After 12-months
Root length (cm)	3.14 ± 0.16	4.41 ± 0.68	4.92 ± 0.31	5.48 ± 0.40	21.7 ± 1.36
Shoot length (cm)	1.6 ± 0.25	2.64 ± 0.32	4.54 ± 1.19	8.46 ± 0.34	10.1 ± 1.10
Number of leaf pairs	1-2	4-7	7-8	8-9	12-20
Root fresh weight (gms)	0.78 ± 0.34	1.1 ± 0.26	1.48 ± 0.23	3.58 ± 0.04	8.82 ± 0.54
Root dry weight (gms)	0.64 ± 0.18	0.74 ± 0.07	1.17 ± 0.09	2.37 ± 0.03	6.52 ± 0.44
Shoot fresh weight (gms)	0.67 ± 0.29	0.81 ± 0.26	1.1 ± 0.21	2.87 ± 0.16	7.06 ± 1.20
Shoot dry weight (gms)	0.49 ± 0.20	0.65 ± 0.07	0.89 ± 0.06	1.23 ± 0.04	4.41 ± 0.49

Figure 1. *Croton scabiosus*: a. & b. Simultaneous flowering and fruiting phases on the same tree, c. & d. Fully developed fruits from female flowers, e. Fruit infestation by unknown insect (exit hole made by it).

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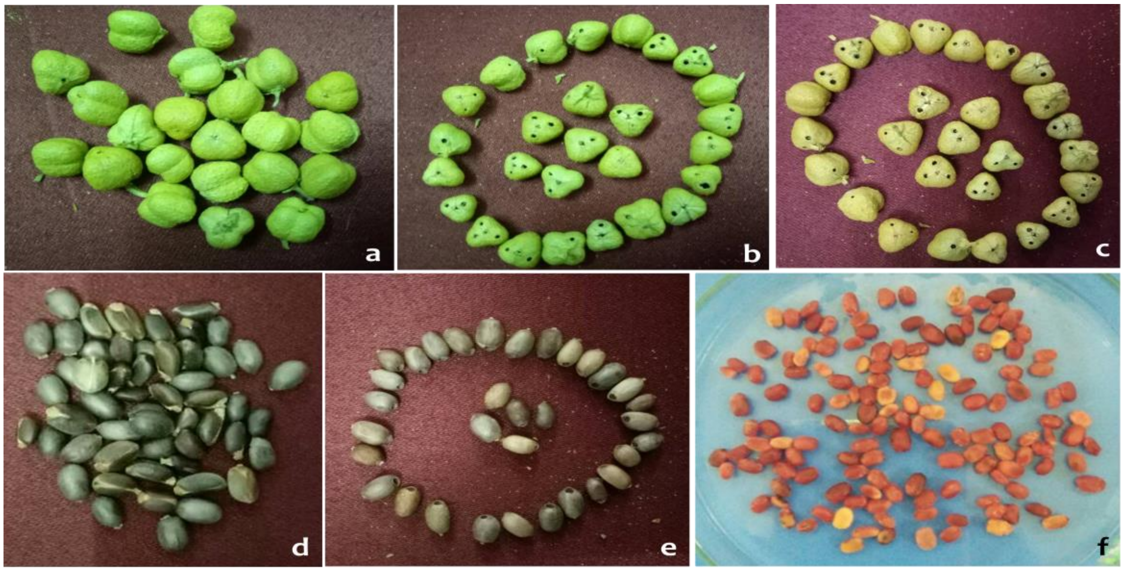

Figure 2. *Croton scabiosus*: a. Maturing fruits, b. Infested maturing fruits, c. Infested mature fruits, d. Mature seeds, e. Infested mature seeds, f. Viable seeds (brick red colour) and non-viable seeds (light yellow colour) when tested with Tetrazolium chloride.

Figure 3. *Croton scabiosus*: a-c. Stages of seedling growth and development in the natural habitat, d. Seed germination and seedlings in experimental polythene bags.

Seed viability:

Testing of seeds collected immediately after their dispersal with 2, 3, 5 Tri Phenyl Tetrazolium Chloride continuously at monthly intervals for 18 months indicated that seed viability was highest (80%) immediately after their fall to the ground, gradually the viability decreased from 72% after 1 month and 2% after 17 months and then they lost viability (Table 2). Viable seeds are brick red while non-viable seeds are light yellow (Figure 2f).

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Effect of different pot media on seed germination:

The effects of different pot media on the seed germination are shown in Table 3. The pot medium, red soil alone and red soil in combination with manure and super phosphate were found to be the best for seed germination. In both pot media, the seed germination rate stood at 80%. Seed germination rate was 53% in black soil medium, 32% in red soil and sand medium, and 20% in sand medium. The time taken for seed germination varied with different pot soil media; the seeds germinated within 13-16 days from the day of sowing in case of red soil combined with manure and super phosphate (3:1:1), 15-18 days in case of red soil without any additional medium, 19-21 days in case of sand medium, 21-23 in case of black soil medium and 24-26 days in case of red soil mixed with sand. Seed germination and seedling aspects in natural habitat and in experimental polythene bags are presented in Figure 3a-c.

Effect of different pot media on seedling growth, production of leaf pairs and biomass production:

Seedling measurements (root length and shoot length), number of leaf pairs, root and shoot fresh and dry weight recorded after 1, 3, 6, 9 and 12 months varied with each pot soil medium. In red soil medium, root length was 2.4 ± 0.35 after 1 month and 14.9 ± 3.55 after 12 months while shoot length was 1.32 ± 0.25 after 1 month and 13.74 ± 1.40 after 12 months (Table 4). In black soil medium, root length was 2.16 ± 0.18 after 1 month and 14.10 ± 2.75 after 12 months while shoot length was 1.24 ± 0.26 after 1 month and 11.80 ± 1.53 after 12 months (Table 5). In red soil and sand medium, root length was 2.06 ± 0.08 after 1 month and 7.16 ± 0.72 after 12 months while shoot length was 1.16 ± 0.18 after 1 month and 3.92 ± 0.59 after 12 months (Table 6). In red soil, manure and super phosphate (3:1:1 ratio), root length was 3.14 ± 0.16 after 1 month and 21.7 ± 1.36 after 12 months while shoot length was 1.6 ± 0.25 after 1 month and 10.1 ± 1.10 after 12 months. The number of leaf pairs produced was 1-2 in all pot media after 1-month; 3-6 in red soil and black media, 3-4 in red soil and sand medium and 4-7 in red soil mixed with manure and super phosphate medium after 3-months; 4-9 in red soil medium, 5-9 in black soil medium, 4-5 in red soil and sand medium, and 7-8 in red soil combined with manure and super phosphate medium after 6-months; 7-10 in both red and black media, 6-9 in red soil and sand medium and 10-13 in red soil combined with sand and super phosphate medium after 9-months. After 12-months, the number of leaf pairs produced was 12-19 in red soil medium, 12-15 in black soil medium, 7-10 in red soil and sand medium, and 12-20 in red soil, manure and super phosphate medium (Table 7). In all pot media, the fresh weight and dry weight of both root and shoot of seedlings gradually increased from the early phase (after 1-month) to the last phase (after 12-months) recorded. But, the weights were the highest in early and late phase in case of pot medium consisting of red soil, manure and super phosphate followed by the weights recorded for seedlings developed in black soil medium, then in red soil medium and finally in red soil and sand medium. Overall, the pot medium consisting of red soil, manure and super phosphate is the most ideal medium for quick growth of seedlings, production of maximum number of leaf pairs and maximum biomass production. Among other pot media, red soil was found to be ideal for quick root and shoot growth by length and the production of maximum number of leaf pairs but black soil was found to be ideal for more biomass production. Pot medium consisting of red soil mixed with sand was found to be unfavorable for quick growth, production of more number of leaf pairs and more biomass production.

4. DISCUSSION

Janzen (1971) and Hulme and Benkman (2002) explained seed predation types and the predator animals associated with them. Seed predation occurs during pre-dispersal and post-dispersal phases. Pre-dispersal seed predation involves the removal of seeds from the parent plant prior to dispersal. This predation is reported mostly in invertebrates followed by birds, and rodents and their life cycle is usually associated with the timing of seed production by the host plant species. Post-dispersal seed predation occurs after seeds have been dispersed from the parent plant. Ants, birds and rodents are mostly involved in this type of predation; they are generalists which use seed source from different plant species that occur on the ground. The seeds dispersed and not consumed would have a chance to germination if the soil conditions are favorable. Plants have evolved defenses to protect seeds from predators. The defenses include seed morphology and chemical compounds produced by seeds. However, seed predators have also adapted to plant defenses by boring seeds or by detoxifying chemical compounds. Lucas et al. (2000) noted that plants increase fruit hardness or toughness to shield against seed predation by investing in fruit hardness or toughness.

Despite various protective measures evolved by plants to protect their seeds, still they are subjected to predation due to their value as a source of food. In *Croton scabiosus*, seed predation occurs in pre-dispersal stage. An unknown insect species uses flower buds as ovi-position sites and the adults emerge during fruit maturation stage. The larvae use the developing endosperm and embryo as food and the adults bore at the chalazal end of the seed and fruit to take exit. The fruit and seeds used can be easily separated as they show a circular hole at the opposite end of the caruncle. It appears that this insect uses particularly this species

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for breeding and feeding during pre-dispersal stage of seeds. This insect uses the seeds to ensure a rich food resource for the development of its progeny (Hulme, 2002). Seeds are valuable for their nutritional content as they are low in water soluble carbohydrates and high in protein, fat, fiber and secondary compounds (Kinzey and Norconk, 1993; Norconk et al. 1998). In *Euphorbia pedroi,* specialist-wasps and generalist hemipterans act as pre-dispersal seed predators for a major fraction of the reproductive losses. *Cydnus aterrimus* is the most common seed predator among generalist seed predators. Pre-dispersal seed predation rate by *Eurytoma jaltica*, *Cydnus aterrimus* and *Dicranocephalus agilis* are high in *E. welwitschii* and low in *E. characias* (Boieiro et al. 2010; Boieiro, 2014). Pre-dispersal predation losses to a moth, *Laspeyresia* sp. is approximately 80% in *Mabea occidentalis* (Steven 1981). Further, Kolb et al. (2007) stated that pre-dispersal seed predation by insects is often more than 50% of the total seed crop. In *C. scabiosus* also, pre-dispersal seed predation is more than 50%; it is 57% to 64% during January-June flowering season and 74% during September-October flowering season. This study substantiates that seed predation by insects is extremely severe as the insects use flower buds for ovi-position and seeds for feeding. Therefore, high rate of seed predation has great implications for population dynamics of this plant.

In *C. scabiosus*, seed predation has no effect on the feeding activity of *Camponotus* ants on the caruncle of seeds because it is still intact and not consumed by seed predator. But, ants disperse both the seeds used and not used by the seed predator. This situation indicates that the success rate of myrmecochory is related to the quantity of seeds not used by the seed predator. The study suggests that high seed predation rate is probably a major factor for the occurrence of small population size of *C. scabiosus* at the forest sites of the present study.

Bonner (1984) mentioned that seed viability is the capacity of the seed to germinate, grow and develop seedling. Reports on seed viability tests indicate that tetrazolium staining test is mostly used to assess the seed viability of different species such as leguminous seeds (Porter et al. 1947), paddy seeds (Venkataratnam, 1951), agricultural and vegetable crop seeds (Mukherji, 1956), forest tree species namely, *Albizzia lebbek, A. procera, A. chinensis, Cassia nodosa* (Gupta and Raturi, 1975), *Chloroxylon swietenia* (Yadav et al. 1986), *Tectona grandis, Acacia catechu, Albizzia procera, Butea monosperma, Dendrocalamus strictus* (Yadav, 1989), *Cassia fistula, Leucaena leucocephala, Bauhinia variegata* and *Wrightia tinctoria* (Babeley and Kandya, 1989; 1990). In the present study also, tetrazolium chloride was used to test seed viability in *C. scabiosus*. The test is found to be ideal for quick and accurate results for seed viability. The seeds are viable for more than one and half year but viability percentage varies; it is highest immediately after seed fall to the ground and gradually decreases to lowest after one and half year and later seeds become non-viable. The study indicates that the seeds of *C. scabiosus* have a long period of viability and have the ability to germinate even after one and half year and produce new plants if soil conditions are ideal.

Harper (1977) stated that seeds require suitable environmental conditions for the growth and establishment of the seedlings. Narbona et al. (2007) stated that viable seeds of some species do not germinate even though conditions are favorable for seedling establishment. Hartmann et al. (1997) stated that three conditions are required for the initiation of seed germination - viability of the seed, ability to overcome seed dormancy and exposure to suitable environmental conditions such as water availability, proper temperature regime, oxygen supply, light and microorganisms that decompose seed coat for seed germination. Leggese and Negash (1995) stated that plants have developed different sensing capabilities to sense the prevailing environmental conditions to fix the timing of seed maturation, germination, and seedling emergence to particular periods of the year. They fix the timings of these processes according to their habitat locations and required environmental conditions. In the present study, the responses of seed germination aspects of *C. scabiosus* to different soil media indicated that red soil combined with manure and super phosphate is most ideal for quick germination, highest germination percentage, quick growth of seedlings, production of maximum number of leaf pairs and maximum biomass production during 12-month period of observation. Red soil medium is also good for quick germination, highest germination percentage, quick root and shoot growth and the production of maximum number of leaf pairs but seedlings show low biomass production when compared to that produced in black soil medium. Sand medium is not an effective for seed germination and subsequent growth and development of seedlings. The study indicates that red soil type and black soil types provide favorable conditions for regeneration of *C. scabiosus* from seeds. The soils of study sites represent rocky terrain with red sandy soil mixed with black soil and this soil type appears to be unfavorable for high seed germination rate and this observation is substantiated by small population size at both the study sites. Salamma and Rao (2013) also reported that *C. scabiosus* in Kadapa district has low regeneration rate due to seed pathogens, poor germination and recurrent fires in its native habitat. Further, Salamma and Rao (2014) reported that seed germination rate varies from 2 to 5% in *C. scabiosus*. Further, these authors also mentioned that *in vitro* propagation method to produce multiple plantlets from *C. scabiosus* did not yield encouraging results. Therefore, the study recommends further field studies on *in situ* soil analysis and seed predation in order to take effective measures for *in-situ* conservation and self-restoration of population by *C. scabiosus*.

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5. CONCLUSION

In *Croton scabiosus*, seed predation occurs in pre-dispersal stage by an unknown insect. Pre-dispersal seed predation is 57% to 64% during January-June flowering season and 74% during September-October flowering season indicating that seed predation rate is very high and hence, has great implications for population dynamics of this plant. *Camponotus* ants feed on the caruncle of the seed, which is not either damaged or used by the seed predator and its feeding activity contributes to seed dispersal which is related to the total seed quantity not used by the seed predator. *C. scabiosus* seeds are viable for more than one and half year but viability percentage varied; it is highest immediately after seed fall to the ground and gradually decreased to lowest after one and half year and later seeds become non-viable. Seed germination in different soil media indicated that red and black soil types provide favorable conditions for seed germination but the soil types of study sites characterized by rocky terrain and red sandy mixed with black soil is unfavorable for seed germination as evidenced by the presence of a small population of the plant. The study recommends further field studies on *in situ* soil analysis and seed predation to take effective measures for *in-situ* conservation and self-restoration of population by *C. scabiosus*.

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Authors contributions:

All authors contributed equally.

Ethical approval

The ethical guidelines for plants & plant materials are followed in the study for species collection & identification.

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Conflicts of interest:

The authors declare no conflict of interest.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Babeley, G.S. and Kandya, A.K. 1989. Use of Tetrazolium chloride for testing the viability of some forest tree species seeds. J. Trop. Fore. 5: 289-298.
2. Babeley, G.S. and Kandya, A.K. 1990. Use of Tetrazolium chloride for testing the viability of some forest tree species seeds. J. Trop. For. 6: 341-349.
3. Bewley, J.D. 1997. Seed germination and dormancy. Plant Cell 9: 1055-1066.
4. Bewley, J.D., Bardfort, K.J., Hilhorst, H.W.M. and Nonogaki, H. 2013. Seeds: Physiology of Development, Germination and Dormancy. Springer, New York.
5. Boieiro, M., Rego, C., Serrano, A.R.M. and Espadaler, X. 2010. The impact of specialist and generalist pre-dispersal seed predators on the reproductive output of a common and a rare Euphorbia species. Acta Oecologica 36: 227-233.
6. Boieiro, M.R.C. 2014. Spatio-temporal variation in seed production in three Euphorbia species and the role of animals on seed fate. Ph.D. Thesis, Universidad da Madeira, Portugal.
7. Bonner, F.T. 1984. Glossary of seed germination terms for tree seed workers. USDA Forest Service Gen. Tech. Rep. 49-50, Southern Forest Experiment Station.
8. Chiruvella, K.K., Mohammed, A. and Ghanta, R.G. 2014. Factors influencing the seed germination of *Soymida ferbrifuga*. Tarkia J. Sci. 2: 121-131.
9. Crawley, M.J. 1992. Seed predators and plant population dynamics. In: Seeds: The Ecology of Regeneration in Plant Communities, M. Fenner (ed), pp. 157– 191. CABI International, Wallingford, UK.

ISSN 2319–5746 EISSN 2319–5754 I OPEN ACCESS

10. Dante, R.A., Larkins, B.A. and Sabelli, P.A. 2014. Cell cycle control and seed development. Frontiers in Plant Science 5: 21-33.
11. Gupta, B.N. and Raturi, A.S. 1975. Tetrazolium staining of seeds for interpretation of viability of six Indian tree species. Ind. For. 101: 659-673.
12. Gupta, S., Bhattacharya, K.N. and Chandra, S. 1989. In vitro pollen germination of Solanum *sisymbriifolium Lamk*. J. Palynol. 25: 65-72.
13. Harper, J.L. 1977. Population biology in plants. Academic Press, New York.
14. Hartmann, H.T., Kester, D.E., Davies, F.Jr. and Geneve, R.L. 1997. Plant Propagation Principles and Practices. Prentice Hall, New Jersey.
15. Hassan, M.A. and Fardous, Z. 2003. Seed germination, pollination and phenology of *Gloriosa superba* L. (Liliaceae). Bangladesh J. Plant Taxon. 10: 95-97.
16. Hulme, P.E. 2002. Seed-eaters: seed dispersal, destruction and demography. In: Seed dispersal and frugivory: ecology, evolution and conservation, D. Levey, W.R. Silva and M. Galetti (eds), pp. 257-273, CABI Publishing, Wallingford.
17. Hulme, P.E. and Benkman, C.W. 2002. Granivory. In: Plant-animal Interactions: An Evolutionary Approach, pp. 132-154, C.M. Herrera and O. Pellmyr (eds.), Blackwell Publishers, Oxford.
18. Janzen, D.H. 1970. Herbivores and number of tree species in tropical forests. The Am. Nat. 104: 501–528.
19. Janzen, D.H. 1971. Seed predation by animals. Ann. Rev. Ecol. and Syst. 2: 465.
20. Kinzey, W.G. and Norconk, M.A. 1993. Physical and chemical properties of fruit and seed eaten by *Pithecia* and *Chiropotes* in Surinam and Venezuela. Intl. J. Primatol. 14: 207-227.
21. Kolb, A., Ehrlen, J. and Eriksson, O. 2007. Ecological and evolutionary consequences of spatial and temporal variation in pre-dispersal seed predation. Perspect. Plant Ecol. Evol. Syst. 9: 79-100.
22. Leggesse Negash 1995. Indigenous trees of Ethiopia: Biology, uses and propagation techniques. SLU Reprocentralen, Umea, Sweden.
23. Lucas, P.W., Turner, I.M., Dominy, N.J. and Yamashita, N. 2000. Mechanical defences to herbivory. Ann. Bot. 86: 913-920.
24. Miles, A. and Brown, M. 2007. Teaching organic farming and gardening: resources for instructors. University of California Farm and Garden, Santa Cruz.
25. Mukherji, D.K. 1956. Seed testing. Investigations on tetrazolium salt as a rapid germination test for seeds of agricultural and vegetable crops. Sci. and Culture 21: 390-391.
26. Narbona, E., Arista, M. and Ortiz, P.L. 2007. High temperature and burial inhibit seed germination of two perennial Mediterranean Euphorbia species. Bot. Helv. 117: 169-180.
27. Narbona, E., Arista, M. and Ortiz, P.L. 2007. Seed germination ecology of the perennial Euphorbia boetica, an endemic spurge of the southern Iberian Peninsula. Ann. Bot. Fennici 44: 276-282.
28. Nonogaki, E.N.H. 2012. Seed biology in the 21st Century: perspectives and new directions. Plant and Cell Physiol. 53: 1-4.
29. Norconk, M.A., Grafton, B.W. and Conklin-Brittain, N.L. 1998. Seed dispersal by neotropical seed predators. Am. J. Primatol. 45: 103-126.
30. Porter, R.H., Durreli, M. and Romm, H.J. 1947. The use of 2,3,5, triphenyl tetrazolium chloride as a measure of seed germinability. Plant Phys. 22: 149-159.
31. Salamma, S. and Rao, B.R.P. 2013. In vitro embryo culture of *Croton scabiosus* Bedd. (Euphorbiaceae), an endemic plant of Southern Andhra Pradesh. IOSR J. Pharm. Biol. Sci. 5: 108-114.
32. Salamma, S. and Rao, B.R.P. 2014. Distribution and conservation status of *Croton scabiosus* Bedd. (Euphorbiaceae), an endemic tree species of southern Eastern Ghats of Andhra Pradesh, India. J. Threatened Taxa 6: 6363-6370.
33. Steven, D.D. 1981. Pre-dispersal seed predation in a Tropical Shrub (*Mabea occidentalis*, Euphorbiaceae). Biotropica 13: 146-150.
34. Venkataratnam, L. 1951. Seed viability test with 2,3,5-triphenyl tetrazolium chloride. Madras Agric. J. 38: 248-251.
35. Yadav, V.K. 1989. Germination studies of selected forest tree seeds with special reference to storage conditions. Ph.D. Thesis Dr. H.S. Gour University, Sagar.
36. Yadav, V.K., Khare, P.K. and Mishra, G.P. 1986. Quick test for viability and vigour in seeds of *Chloroxylon sweitinia*. J. Trop. For. 2: 213-216.

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